xv. Energy Extraction System

Even though the individual magnet that quench is protected, it is necessary to remove the stored energy from the entire series-connected string of magnets as rapidly as possible to protect buses and diodes from overheating. The thermal mass of these elements is large enough to permit a simple solution. Figures 2-2 and 2-3 show the energy extraction systems for dipole and quadruples circuits. The main elements used in the energy extraction system for the main circuits are the SCR switches and dump resistors.

The SCR switches consist of six SCR in parallel (see Fig. 2-27). The SCR's are normally conducting when the circuit is operating normally. To insure even current sharing a current sharing resistor is in series with each SCR. The SCR's are specifically selected to have low initial turn on voltage characteristics. The current sharing resistor is size to balance the current at 6000 amps to approximately 10 percent. The switch will open when the energy stored in the pulse forming network is connected across the bank of SCR's by the trigger SCR. This will back bias the six parallel SCRs off. The voltage levels on the capacitors in the pulse forming network are fixed. This voltage level is what's required to open the switch at an operating current of 6700 amps from going through the switch. If the voltage is below this level it to will not have sufficient energy turn the SCR off. The snubber diodes stack is used to limit voltage transients when the pulse forming network is applied across the SCR bank at much lower currents (< 2000 amps). The D.C. interrupter is used as a backup in the SCR's do not open.

A PLC monitors status' and fault conditions of the SCR switch. It also performs control functions of closing and opening the switch by local and remote control.

The dump resistors are large stainless-steel resistors of sufficient mass to limit the temperature rise to acceptable limits after each energy extraction. They are cooled by natural convection. The resistance values are selected to balance the requirements of being able to remove the current fast enough to protect the cryogenic diodes or bus work and to limit the voltage transients from bus to ground and between buses during an energy extraction. The system is now designed to keep the worst-case bus quenches limited to a little over half its allowed maximum temperature rise. For the worst-case condition of a complete magnet group quenching the maximum voltage to ground is 780 volts and bus to bus voltage of 1500 volts.

The basic switch used in building 1004B in the main circuit Output Circuit Compartment (OCC) is of the same design as used in building 1010A. (same PFN, SCRs, snubber diodes stack, D.C. interrupter, interlocks, etc.) The main difference is the placement of the dump resistors across the circuits. Also there are blocking SCRs that prevent current from flowing in the dump resistors under normal power supply operation (see Fig. 2-2). These blocking SCR's are triggered when there is an energy extraction. The reason the SCR is used here is because the main power supply can operate in the invert mode and generate a large negative voltage. If diodes are used instead of SCR's significant current would flow through the diodes when the power supply went into the invert mode.

Insertion Region Circuits

The insertion region of magnet circuits of RHIC is very complex. There are power supply circuits nested within each main circuit at the six crossing regions. (See Figs. 2-9, 2-10, and 2-11) The nesting of the various circuits makes this region the most difficult to quench protect. The superconducting buses have been sized to match the nominal operating current of the shunt power supplies. At times different size conductors were used in the same circuit. With these different size conductors there are various limits to the amount of energy these conductors can absorb. During a bus quench one has to keep the conductors below the maximum temperature or a fault could occur. The maximum temperature limit varies depending on many factors. The most critical factor is the type of insulation used on the bus wiring. Where Tefzel is used to maximum temperature is 445 degrees Kelvin, or a temperature rise of 440 degrees Kelvin. If this limit is exceeded one could get insulation failure that can cause a short to ground or circuit to circuit short.

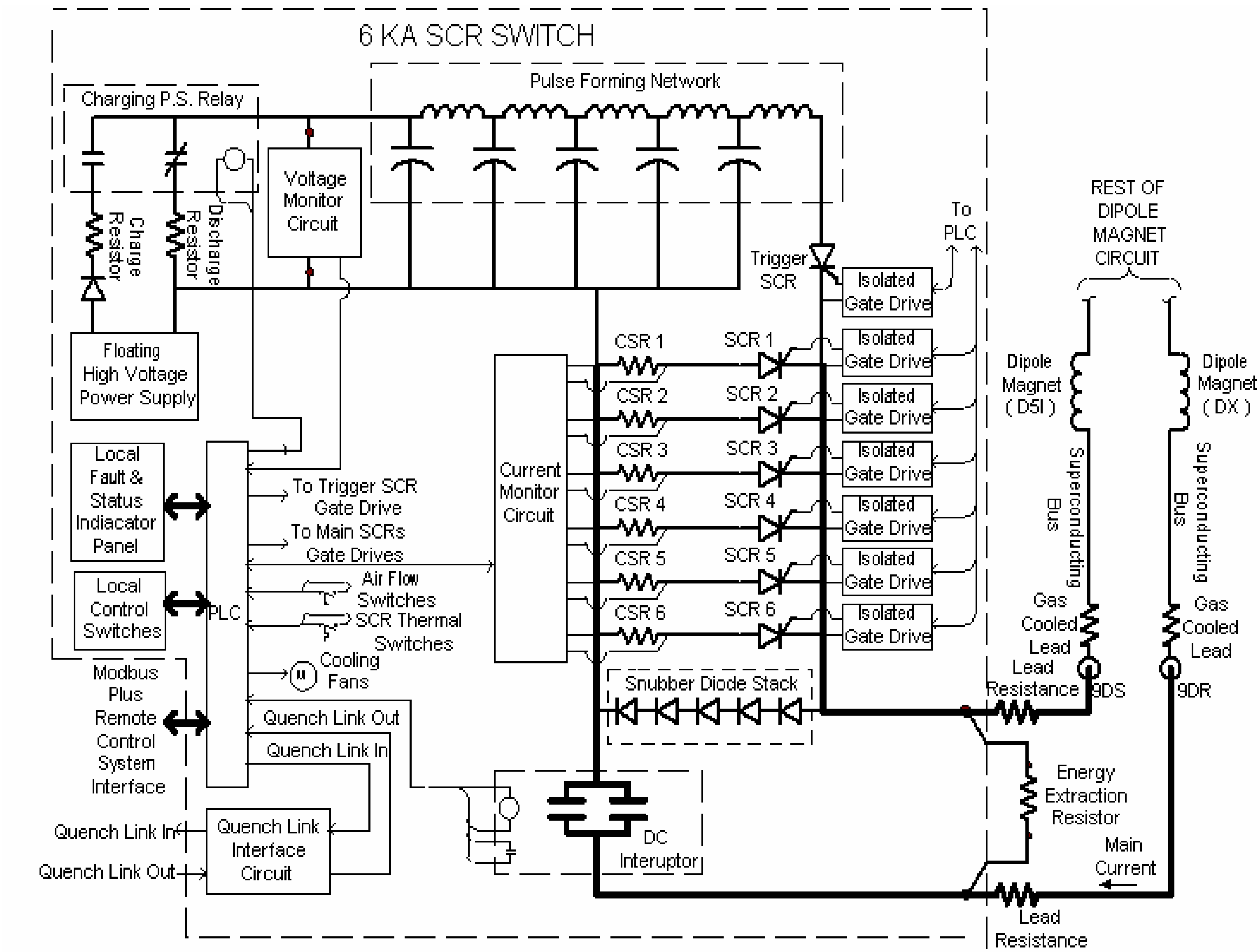

Fig. 2-27 6K SCR Switch

Current in the shunt circuits are at times significantly higher than the current in main circuit. (DX operates at 6400 amps when the arc dipole is that 5050 amps at the top energy of the machine.) During energy extraction significant voltage is undeveloped across the magnet elements. Large currents that could quench the bus will flow in the shunt buses if some action is not taken. If a bus quench work to happen the resistance growth of the quench can be so slow that in most cases it will not decrease the current fast enough to keep the energy deposited by the quench below the safe limit for that bus. Some of the shunt power supplies are configured to subtract current from the main circuit and during an energy extraction the voltage and current flow will reverse.

For all the different insertion magnet circuits there is a unique quench protection assembly (QPA) . These QPAs limit the current of its shunt bus, cause the current in its shunt bus to decrease fast enough to protect the bus, prevent excessive current flow in the power supply, and prevent excessive voltage transients from occurring during main circuit energy extraction. The QPAs are sized to match the current ratings of the various insertion region power supplies.

There are two types of QPAs , an active QPA for high inductance shunt circuits and a passive QPA for low inductance shunt circuits. (See Figs. 2-28, 2-29) The active QPAs use an IGBT (insulated gate bipolar transistor) switch to put a resistance in series with the shunt circuit. This will limit the current in the circuit and cause the current to decrease rapidly. If the IGBT short-circuits during an energy extraction, large currents could flow that will cause the fast acting fuse to blow and thus putting the energy extraction resistor in series with the shunt circuit. The blocking diode is to prevent large reverse currents from flowing through the internal freewheeling diode of the IGBT. The crowbar SCR prevents the current in the shunt circuit from circulating in the power supplies' output stage. It also prevents any large voltage transients that could result in a change in current direction when the main circuit is doing an energy extraction.

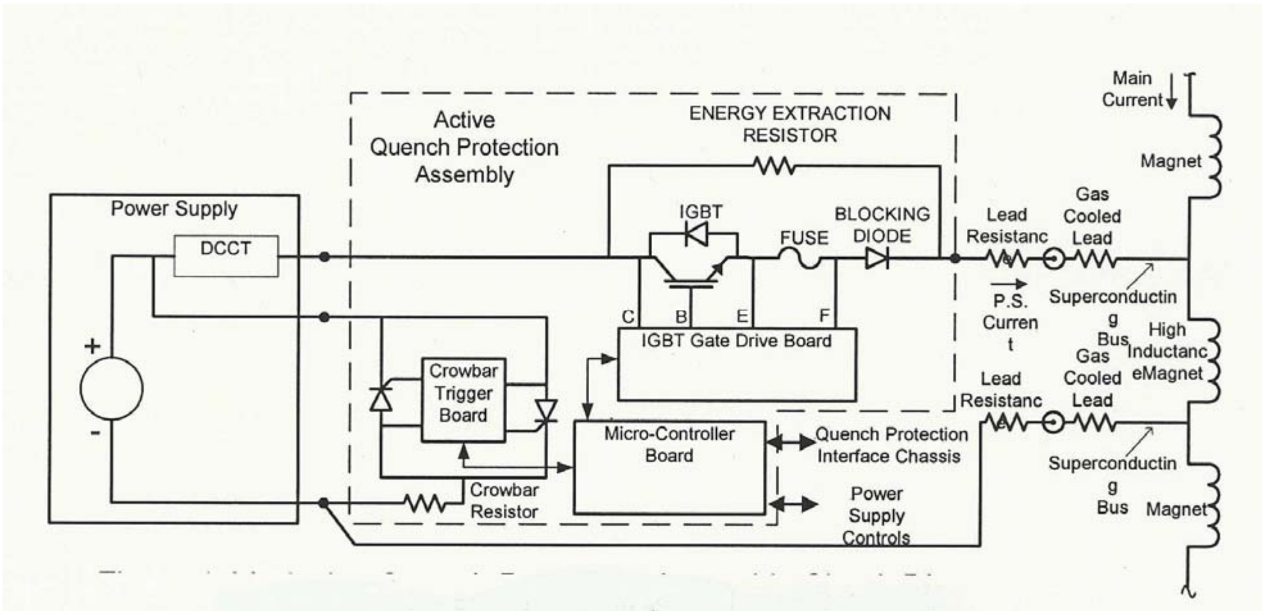

Fig. 2-28 Active quench protection assembly circuit diagram

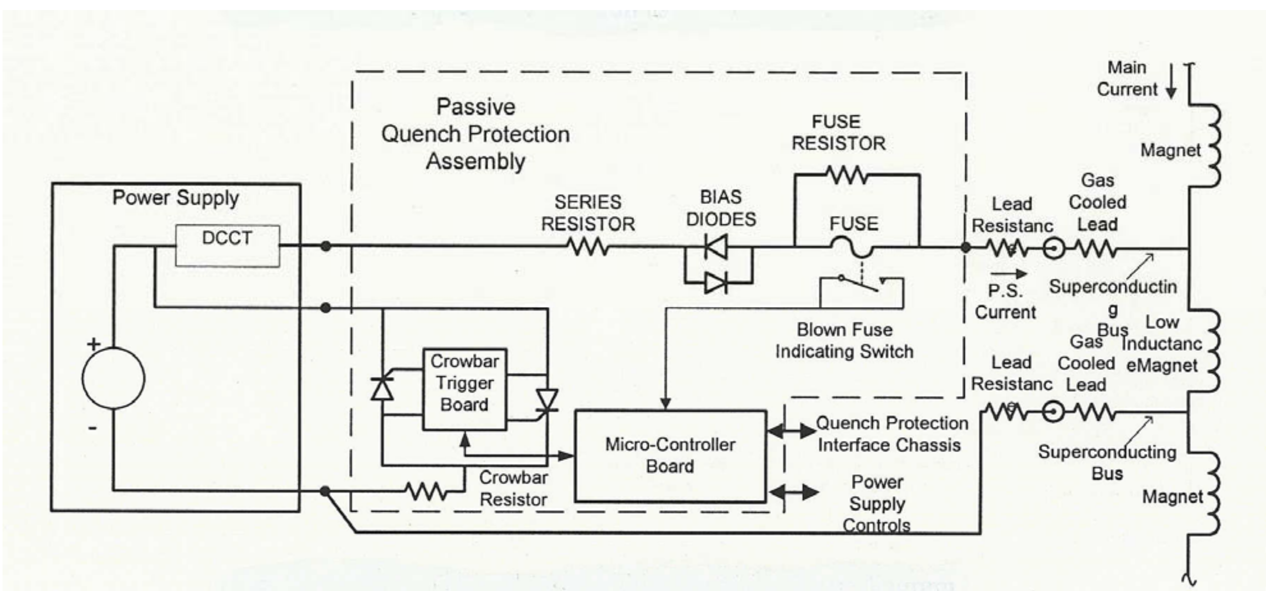

Fig. 2-29 Passive quench protection assembly circuit diagram

The passive QPAs use a simple series resistor and back-to-back biasing diodes to limit the current and enable it to decrease fast enough during the main circuit energy extraction. The fast acting fuse is also used in case there is a condition of high current (shorted crowbar SCR and/or shorted biasing diodes). The crowbar circuit functions the same way as in the active QPA.

Both active and passive QPAs have the same controls. A microcontroller monitors and reports status of interlocks and operational state of the QPAs. It also controls the IGBT and crowbar circuits by input signals from the power supply it is connected to and the quench link signal.

The Quench Protection for Trim Quads, Sextupole, and 50 Amp Corrector Circuits

The trim quad circuits have a high inductance of approximately 0.7 henrys. The single magnet that makes up the trim quad circuit is self protecting but the bus is not. The quench propagation speed of a trim quad bus quench is very slow. If a trim quad bus quench were to occur at maximum current the resistance growth could be too small to decrease the current fast enough to prevent damage to the trim quad bus. Therefore all trim quad magnet circuits use an active QPA to ensure that the current decreases fast enough to protect the trim quad bus.

Sextupole circuits have the largest inductance of all magnet circuits, it is approximately 9.6 henrys. The circuit consists of 12 sextupole magnets connected in series. External SCR crowbars are installed across each magnet. These SCR crowbar circuits have a self trigger circuit that will cause the SCRs to turn on when there is sufficient voltage across the magnet coil. The necessary voltage level and polarity will occur only during a magnet quench to trigger the crowbars. The SCR crowbars are mounted on a large heat sink to prevent the crowbar circuit from overheating while current in the magnet string is brought to zero by an active QPA. This QPA has a slightly different topology then the trim quad or insertion region shunt QPAs to prevent damage of the FET output stage on the sextupole power supplies. The SCR crowbars across each magnet and the active QPA also limits the maximum voltage off ground during a quench and energy extraction for the sextupole circuit. The voltage is kept under 250 volts. This relatively low value is due to a known weakness in the insulation of the internal bus of the sextuple magnets.

All the magnets used in the 50 amp corrector circuits are self protecting for currents up to 60 amps. Therefore the only quench protection needed for the circuits is to shut off the power supply powering them. The 50 amp power supplies have an over-voltage detection and crowbar circuit. The detection circuit will shut off the power supply when the circuit voltage exceeds a fixed limit.